Dynamics of the Migdal effect in isolated atoms

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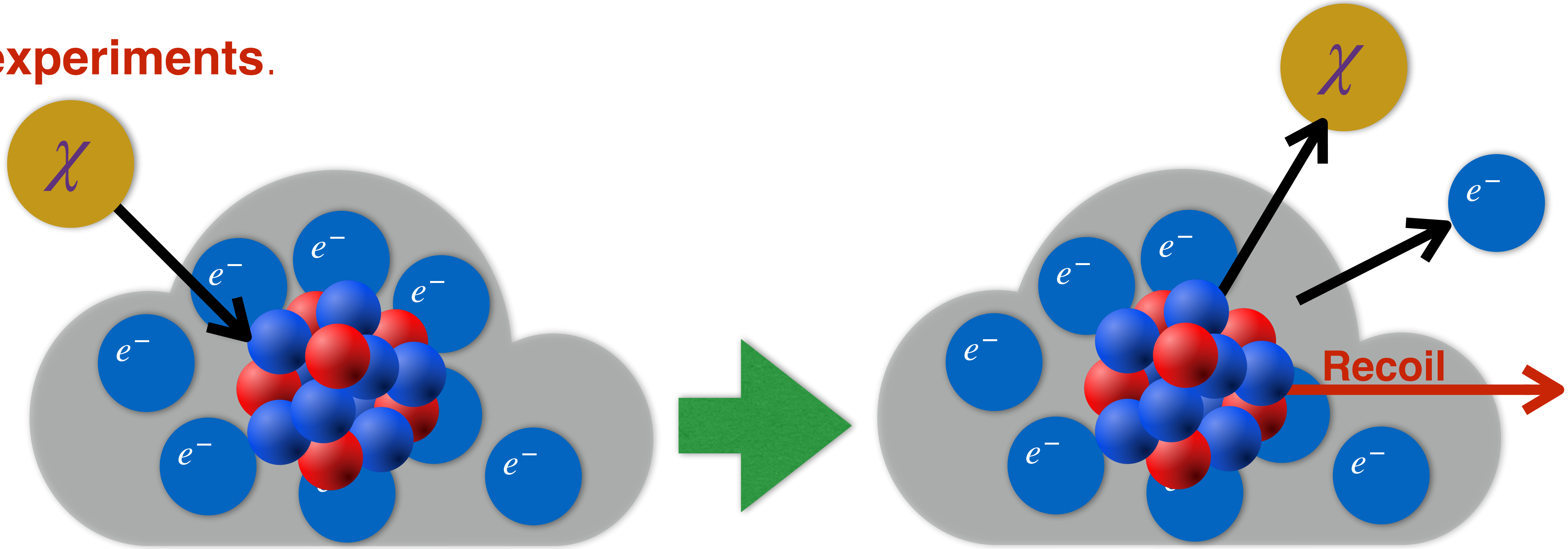
The Migdal effect in isolated atoms

- When an **atom changes its motion**, there is a small probability of the **electronic state transitioning.**
- This can happen during a **scattering** event, eg. **by a DM particle.**
- Emission of Migdal electrons **extends sensitivity of direct detection experiments**.



The Migdal effect in isolated atoms

- When an **atom changes its motion**, there is a small probability of the **electronic state transitioning.**
- Is there an **effect from time-dependence?**
- Does this change the Migdal rate?
- **Study the Migdal effect for an atom first.**

Semiclassical approach to Migdal dynamics

- Use **classical trajectory** of the scattered atom.
- Separate explicit time-dependence: $\hat{p}_j \to \hat{p}_j + m_j \vec{v}(t)$.
- **Generalized boost operator connects asymptotic states:**

$$\mathscr{B}(t \to \infty) = \mathrm{G}(\vec{v}), \quad \mathscr{B}(t \to -\infty) = 1.$$

- Depends on classical trajectory at finite times.
- Find effective Hamiltonian during "acceleration".
- Identify **operator responsible for electronic transitions:**

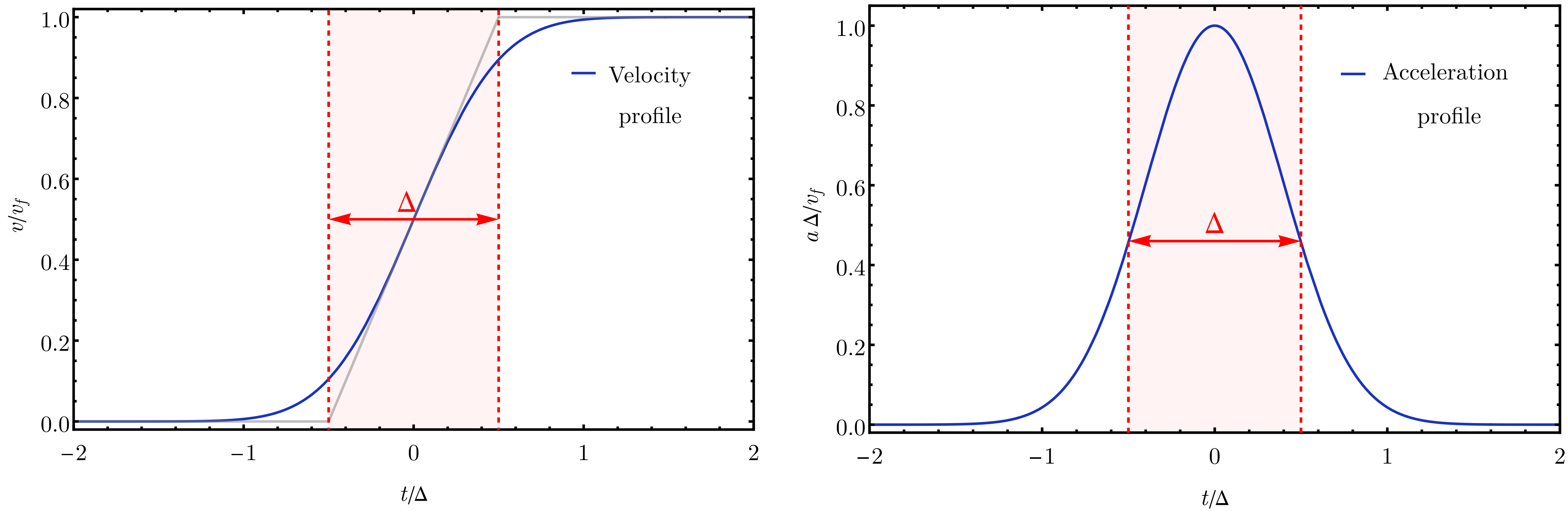
$$m_e \vec{a}(t) \cdot \sum_i \hat{x}_i$$

$$\vec{a}(t) = \partial_t \vec{v}(t)$$

→ Transition occurs during period Γ, where $\vec{a}(t)/v_f \sim 1$.

Semiclassical approach to Migdal dynamics

- Use **classical trajectory** of the scattered nucleus.



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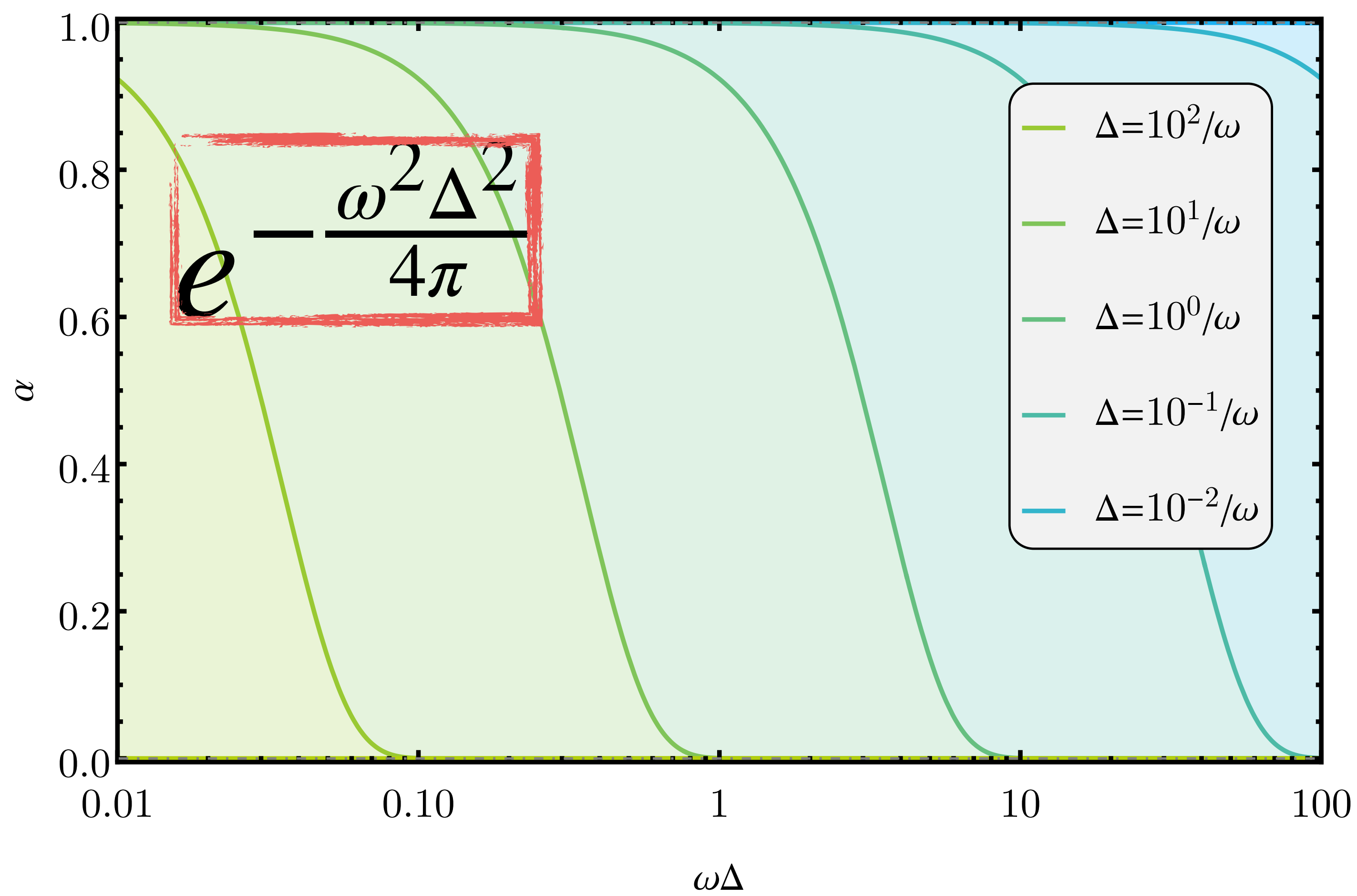
Impact of interaction time on transition rates

- **Interaction time manifests in Migdal rates.**
- Time delay is introduced via Fourier transform of acceleration profile.
- Contribution amounts to a **suppression factor $\alpha(\omega\Delta)$.**



Suppression acts as a cutoff for the Migdal probability.

$$\frac{\mathrm{dp}}{\mathrm{d}\omega} = \alpha(\omega\Delta)\frac{\mathrm{dp}}{d\omega}\bigg|_{\Delta=0}$$

This applies to all orders perturbation theory.

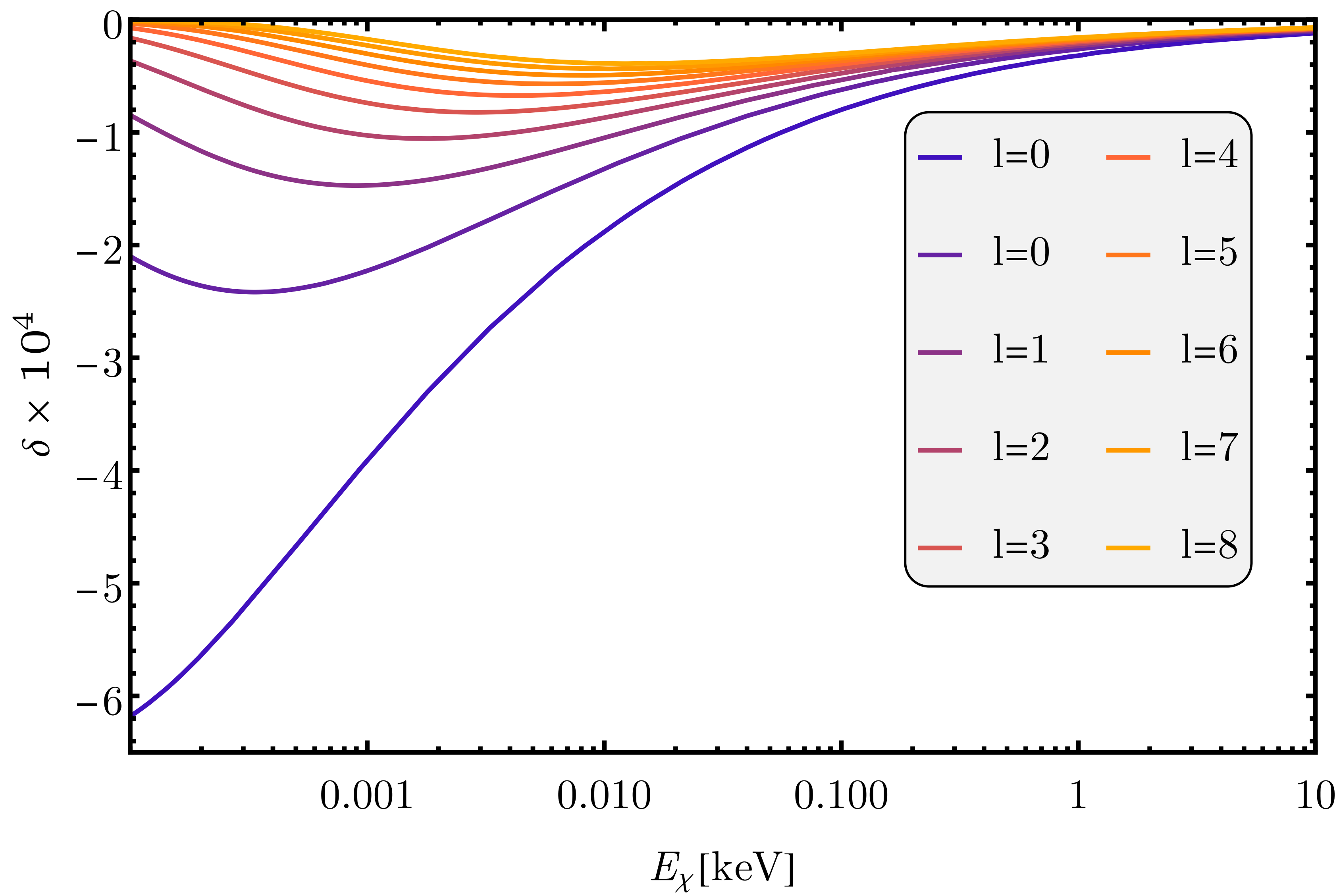
The quantity $\omega\Delta$ emerges as a measure of adiabaticity.

Phase shifts and interaction times

- The phase shift can be used to determine the interaction time.
- This amounts to **solving the radial Schrödinger equation for different DM energies** in the effective range formalism.

$$V = \frac{\kappa}{r} e^{-r m_\phi}$$
$$m_\chi = 10\,\mathrm{GeV}$$
$$m_\phi = 1\,\mathrm{keV}$$
$$\kappa = \frac{10^{-6}}{4\pi}$$

Hitting Xenon



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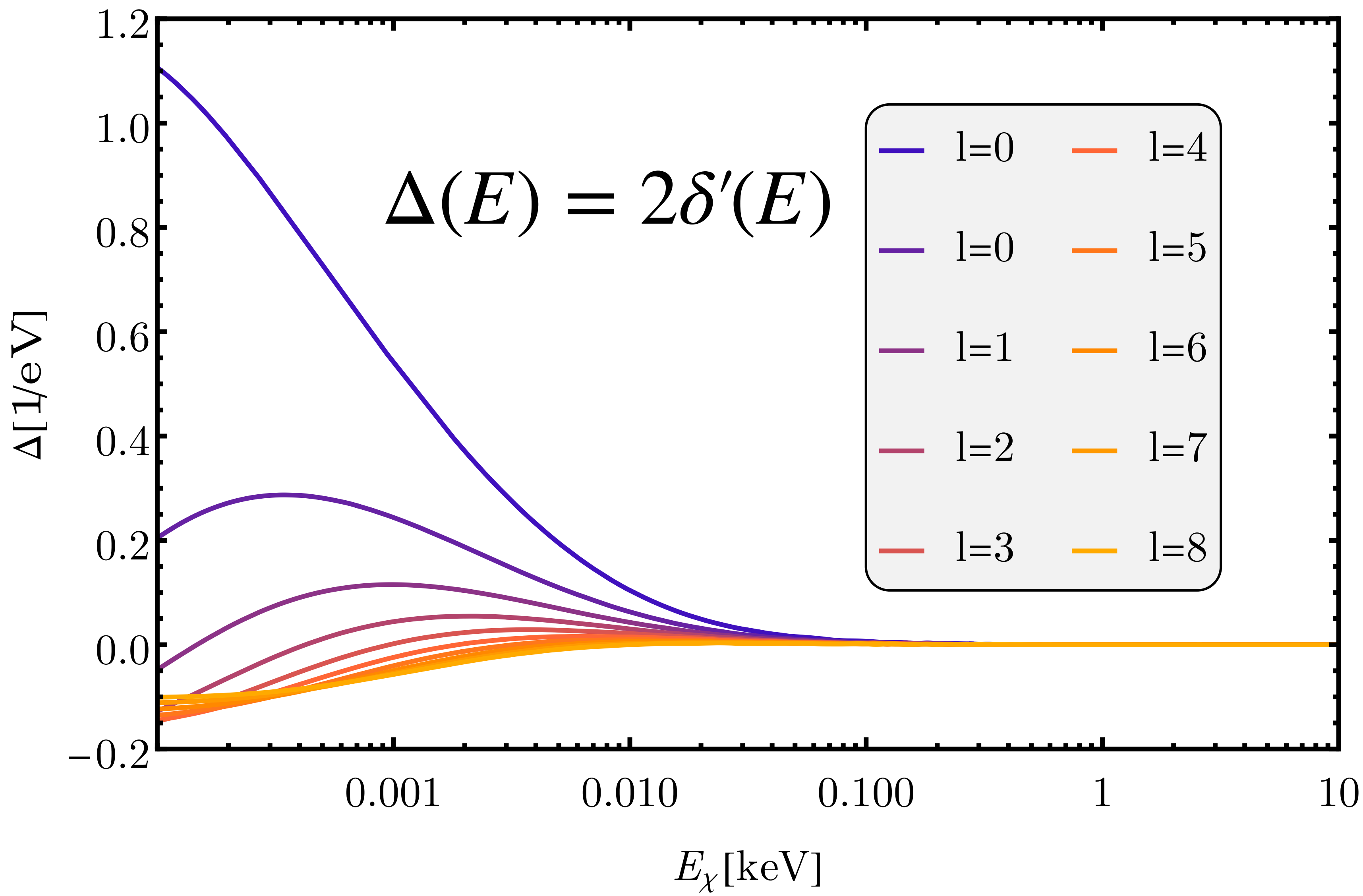

Concluding remarks

- Migdal effect possess **an adiabatic threshold.**
- Holds up to higher orders in perturbation theory.
- Cutoffs/absence in/off **Migdal rates contain information about DM-nucleus interaction.**
- Go beyond semiclassics or/and effective range approach.
- **Study more complex systems.**